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Co-eruptive subsidence and post-eruptive uplift associated with the 2011–2012 eruption of Puyehue-Cordón Caulle, Chile, revealed by DInSAR

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ABSTRACT

The 2011–2012 eruption of the Puyehue-Cordón Caulle volcanic complex, southern Andes (Chile), was associated with complex surface deformation affecting an area of roughly 50 by 50 km. We report here differential SAR interferometry (DInSAR) results of pre-, co- and post-eruptive deformation from ENVISAT ASAR, COSMO-Skymed, and ALOS-2/PALSAR scenes acquired between early 2011 and early 2017. No clear pre-eruptive deformation is observed during five months before the eruption, although some patterns could be interpreted as showing inflation occurring between April and May 2011. Co-eruptive interferograms show a complex deformation pattern consisting in a major deflation lobe (120 cm LOS lengthening) centered 10 km NW of the eruption vent accompanied by smaller uplift and subsidence regions in the vicinity of the vent. *Re*-inflation began immediately after the end of the eruption. A first pulse lasted 3 years between 2012 and 2015, accumulating ~70 cm uplift. We detect here a second pulse, beginning in June 2016 and still ongoing in February 2017, reaching 12 cm in half a year. Inverse modeling with spherical cavity and spheroidal sources locates re-inflation sources at a depth ranging between 8 and 11 km under the surface. It suggests re-filling of the reservoir occurring after the draining of a shallow magma chamber during the 2011–2012 eruption.

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1. Introduction

Large volcanic eruptions are frequently accompanied by pre-, co- and/or post-eruptive surface deformation (Dzurisin, 2006). Generally, surface uplift or inflation occurs before eruptions, when magma is ascending, whereas subsidence or deflation occurs during or after eruptions, when magma pressure is released (Van der Laat, 1996; Dzurisin, 2006). However, deformation patterns associated to volcanic eruptions can be quite variable and complex in terms of magnitude, location and timing (e.g. Fournier et al., 2010). Measuring and interpreting eruption-related deformation is important because it can help to constrain the eruptive mechanisms and sources, and ultimately the behavior of the magmatic system. In many cases, ground deformation constitutes also a valuable eruption precursor for early-warning systems (Sparks, 2003; Vogfjörd et al., 2005).

Differential SAR Interferometry (DInSAR) is a geodetic technique based on remotely sensed data and used to detect and study surface deformation phenomena (Massonnet et al., 1993). It exploits phase information provided by Synthetic Aperture Radar (SAR) scenes acquired under strictly controlled conditions. Images acquired before and after a deformation event are combined to form a differential interferogram after topographic compensation. Differential interferometric phase is proportional to the Line of Sight (LOS) projection of the ground deformation accumulated during the time span between the scenes acquisitions.

DInSAR has proven to be very useful for studying volcano deformation as it can detect small surface displacements at high spatial resolution (Dzurisin and Lu, 2006). The results can reach uncertainties below 1 cm for large datasets so atmospheric signals can be largely reduced (Casu et al., 2006). Several recent studies highlight the many possible eruption-deformation behaviors, including pre-eruptive inflation followed by co-eruptive subsidence: Grimsvötn (Sturkell et al., 2003), Sierra Negra (Geist et al., 2007), Okmok (Mann et al., 2002), Augustine (Lee et al., 2010), Soufrière Hills (Wadge et al., 2006); co-eruptive subsidence: Westdahl (Lu et al., 2003), Galeras (Parks et al., 2011); pre-

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eruptive inflation and lack of distinct co-eruptive deflation: Eyjafjallajökull 2010 flank eruption (Sigmundsson et al., 2010); co-eruptive uplift: Tungurahua (Biggs et al., 2010); co-eruptive uplift superimposed on a broad subsidence: Fernandina, (Chadwick et al., 2010); no detectable eruption-related deformation: Shishaldin (Moran et al., 2006), Lascar (Pavez et al., 2006); and complex subsidence and uplift patterns related to normal faulting and dyke intrusion before and during an eruption: Oldoinyo Lengai (Baer et al., 2008).

The 2011–2012 eruption of Puyehue-Cordón Caulle, southern Chile, has been one of the major eruptions of the past years, with both explosive and effusive activity and a calculated Volcanic Explosivity Index (VEI) of 4 (Bonadonna et al., 2015). The vent location, magnitude of the co-eruptive deformation reaching >1 m and its location (Jay et al., 2014), seismicity migration (Cardona et al., 2012), and eruption style suggest a massive dike intrusion (Castro et al., 2013), although its importance is not well-understood due to lack of data in the near field (Wendt et al., 2017). From the geophysical point of view, it is the only rhyodacitic eruption that has been monitored with real time instrumentation. Furthermore, re-inflation began almost immediately after the end of the eruption, reaching 70 cm in 4 years (Delgado et al., 2016), and we report here a new inflation pulse of 12 cm in half a year.

In this contribution, we process ALOS2/PALSAR data acquired between early 2015 and early 2017, which shows a second uplift episode occurring after the 2011–2012 eruption. High interferometric coherence provided by L—band data represent an improvement in the deforming pattern characterization, if compared with previous X— and C— band results. We also analyze ENVISAT ASAR data acquired between five months before and nine months after the eruption, and COSMO-Skymed data acquired between 2012 and 2014, and analyze pre-, co- and post-eruptive evolution of the system.

The article is organized as follows: Section 2 outlines the study area and describes the 2011–2012 eruption. Section 3 presents the available dataset and the processing methodology. Section 4 details the results. Section 5 is devoted to the discussion and Section 6 presents the conclusions.

2. Study area

The Puyehue-Cordón Caulle volcanic complex (PCCVC) is located at 40.5°S, 72.2°W, in the active frontal arc of the Andean southern volcanic zone (SVZ) (Fig. 1). It is the largest complex of the SVZ (735 km^3 according to (Völker et al., 2011) and a long-lived volcanic system, active since at least 314 ka (Singer et al., 2008).

The PCCVC consists of the Puyehue stratovolcano and the Cordón Caulle fissure system forming a NW-elongated graben (Fig. 1). The modern complex sits atop a broad older basaltic-andesitic shield

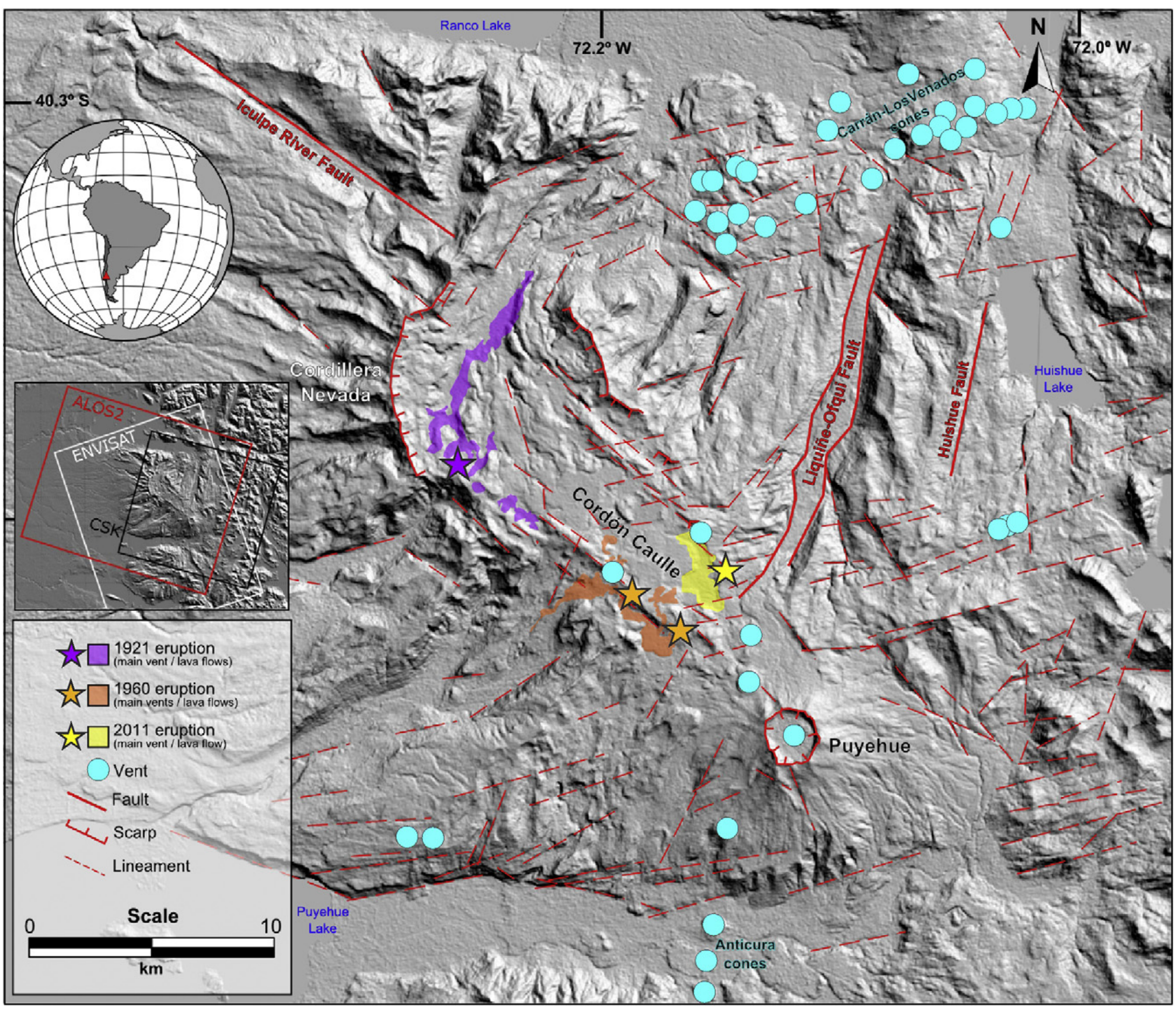

Fig. 1. Shaded-relief image of the PCCVC region showing main vents and lava flows of the 1921–1922, 1960 and 2011–2012 eruptions. Other vents, structures and lineaments are also shown. Insets show the PCCVC location in South America and the footprint of processed SAR data.

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